Proton Driver

CRYOGENICS

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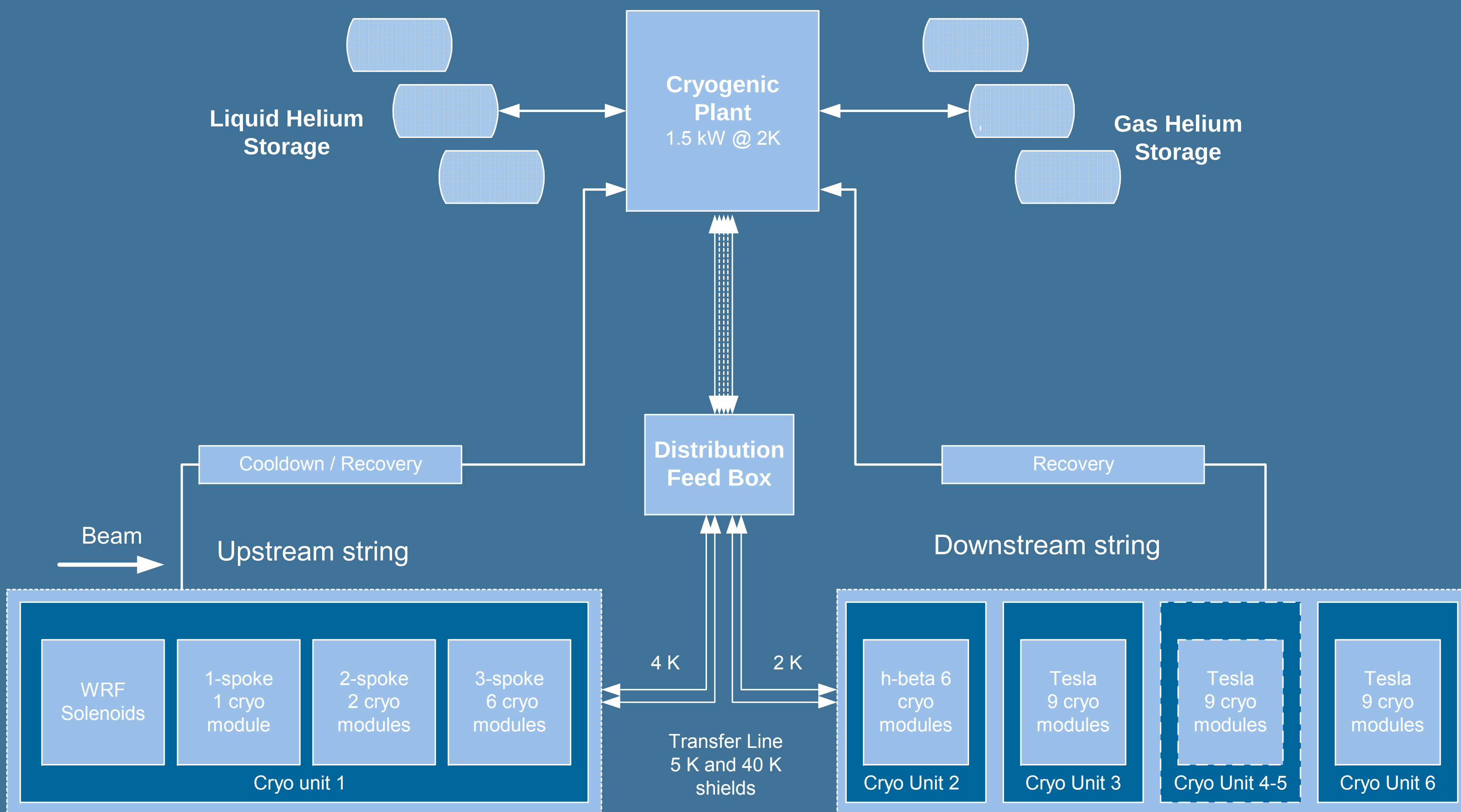
Cryogenic Department

Overview

- Proton Driver (PD) Cryogenics
  - Layout of cryo-units and cryo-strings
  - Cryogenic distribution system
  - Heat Loads
  - Refrigerator size
  - Technology of helium refrigerators
  - Model refrigerator
  - Plant controls
  - Ancillary systems
  - Cryonomics
  - Challenges
  - Conclusions

Cryogenic Layout

Spoke Option



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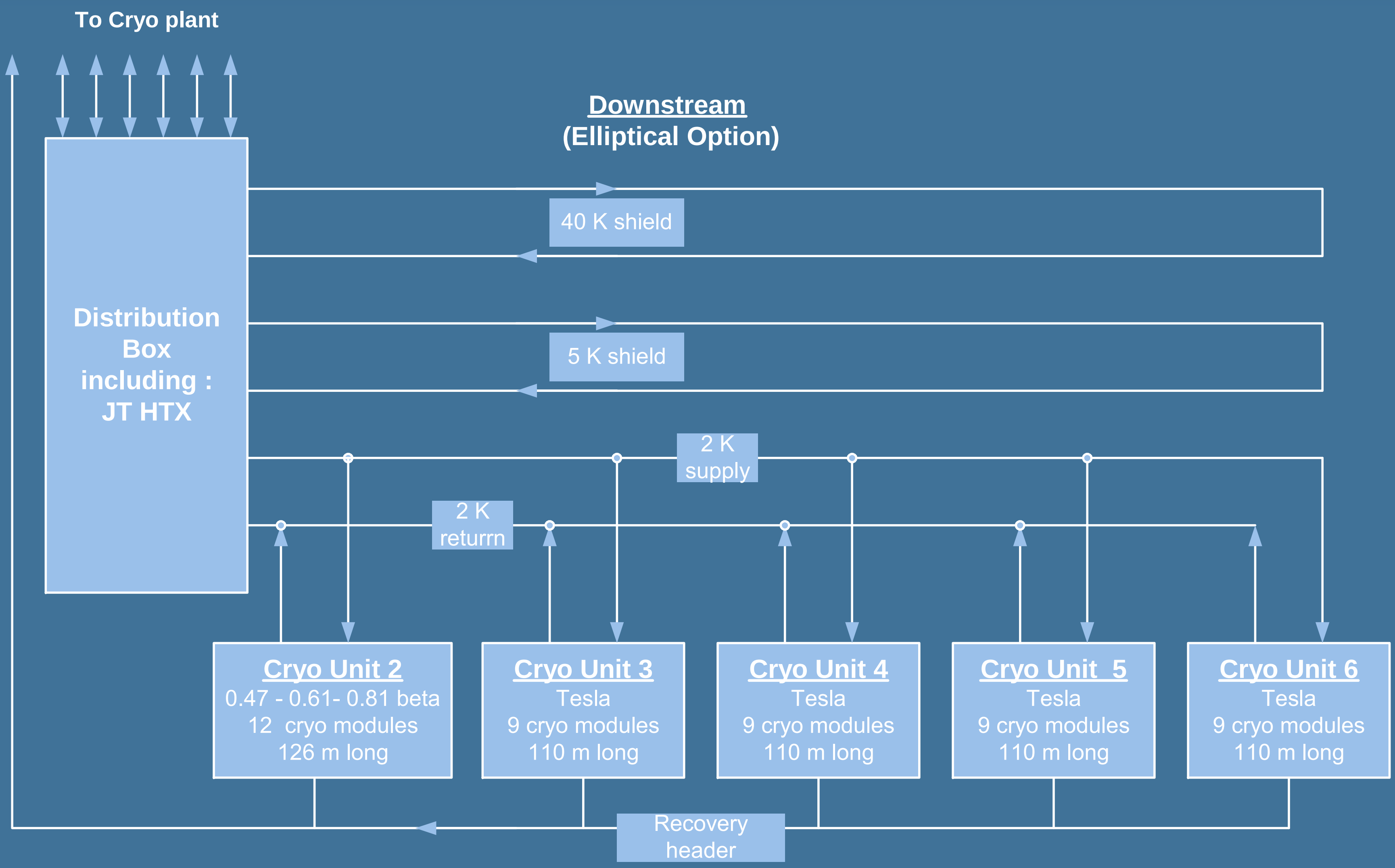
Downstream String



Cryogenic Unit

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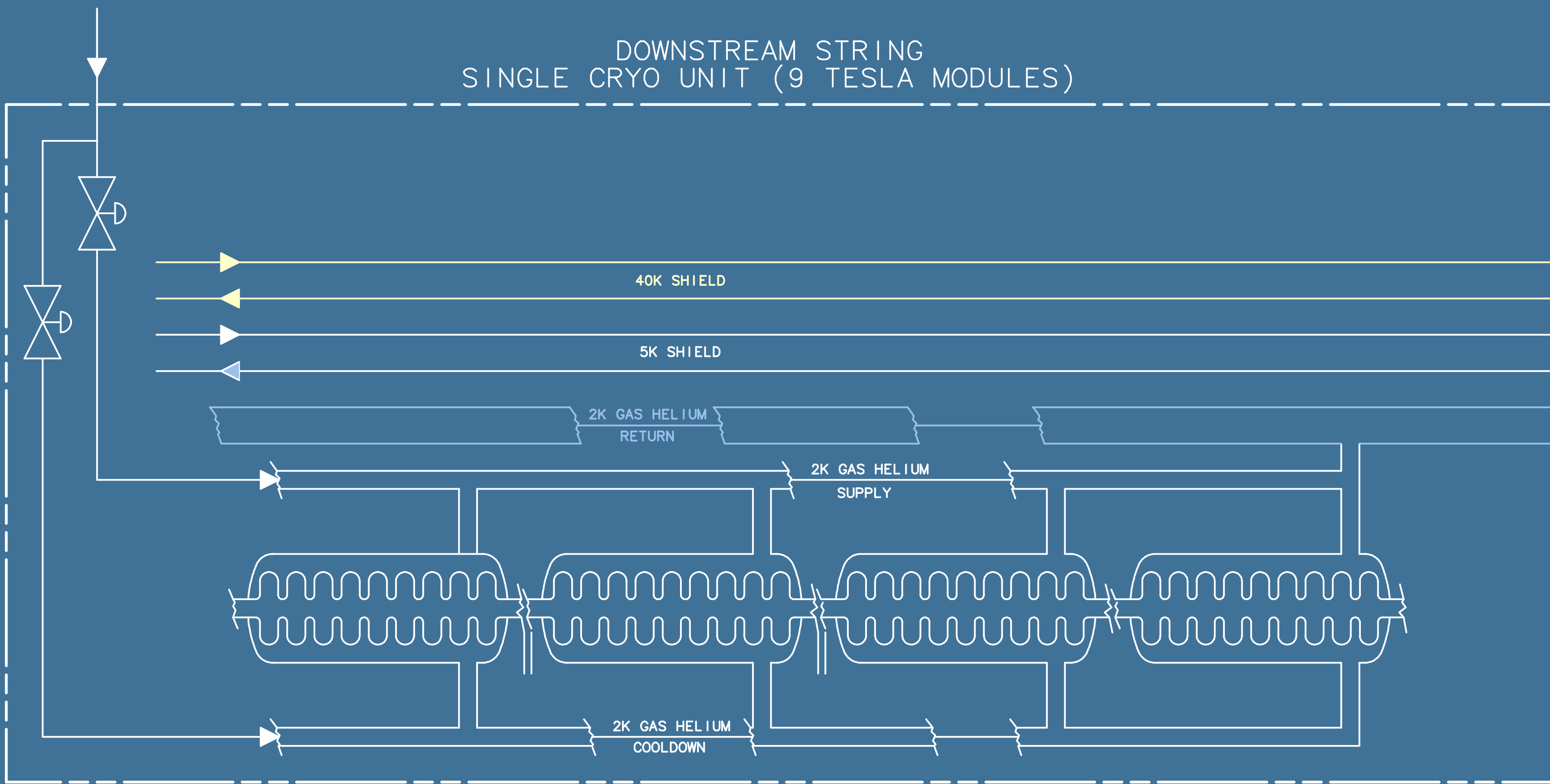

Cryogenic Distribution System

- Low pressure cryogenic transfer line
- High pressure cryogenic transfer line
- Bayonet cans
- Expansion boxes
- Upstream string feed box and end caps
- Downstream string feed box and end caps
- Gas helium header

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Heat Load – Spoke Option

Proton Driver Spoke Option	Qty [#]	Heat Load							
		2K		4K		5K		40K	
Item		Static	Dynamic	Static	Dynamic	Static	Dynamic	Static	Dynamic
Solenoid WRF (NbTi)	25	-	-	500	-	-	-	1144	-
Single Spoke Resonator CM	1	-	-	64	10	-	-	-	-
Solenoid 1spoke	16	-	-	32	-	-	-	-	-
Double Spoke Resonator CM	2	-	-	157	17	-	-	-	-
Triple Spoke Resonator CM	6	-	-	343	91	-	-	-	-
Solenoid 2 spoke	14	-	-	28	-	-	-	-	-
Low Beta CM	0	-	-	-	-	-	-	-	-
Mid Beta CM	0	-	-	-	-	-	-	-	-
High Beta CM	6	24	72	-	-	78	46	541	868
TESLA CM	36	145	433	-	-	468	274	3,245	5,208
End Boxes	4	8	-	10	-	30	-	300	-
Transfer Line	1	4	-	20	-	40	-	200	-
Estimated, [W]		182	505	1154	117	616	319	5,429	6,076
Dynamic to Static Ratio		2.8		0.1		0.5		1.1	
Static to Total Ratio		**26 %**		91%		66%		47%	
Total Estimated, [W]		687		1,271		935		11,506	
Uncertainty Factor		1.3		1.3		1.3		1.3	
Capacity Required, [W]		**893**		**1,652**		**1,216**		**14,958**	

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Heat Load – Elliptical Option

Proton Driver Elliptical Option	Qty [#]	Heat Load							
		2K		4K		5K		40K	
Item		Static	Dynamic	Static	Dynamic	Static	Dynamic	Static	Dynamic
Solenoid WRF (NbTi)	25	-	-	500	-	-	-	1144	-
Single Spoke Resonator CM	1	-	-	64	10	-	-	-	-
Solenoid 1spoke	16	-	-	32	-	-	-	-	-
Double Spoke Resonator CM	2	-	-	140	17	-	-	-	-
Triple Spoke Resonator CM	0	-	-	-	-	-	-	-	-
Solenoid 2 spoke	14	-	-	28	-	-	-	-	-
Low Beta CM	2	8	24	-	-	26	15	180	289
Mid Beta CM	4	16	48	-	-	52	30	361	579
High Beta CM	6	24	72	-	-	78	46	541	868
TESLA CM	36	145	433	-	-	468	274	3,245	5,208
End Boxes	4	8	-	10	-	30	-	300	-
Transfer Line	1	4	-	20	-	40	-	200	-
Estimated, [W]		206	578	794	26	694	365	5,970	6,944
Dynamic to Static Ratio		2.8		0.03		0.5		1.2	
Static to Total Ratio		**26 %**		97%		66%		46%	
Total Estimated, [W]		784		820		1,059		12,915	
Uncertainty Factor		1.3		1.3		1.3		1.3	
Capacity Required, [W]		**1,019**		**1,067**		**1,377**		**16,789**	

Refrigerator Size

Spoke Option	2K	4K	5K	40K	TOTAL
Capacity Required, [W]	893	1,652	1,216	14,958	
Overcapacity Factor	1.5	1.5	1.5	1.5	
Design Capacity, [W]	1,340	2,478	1,824	22,436	
4.5K equivalent, [W@4.5K]	3,282	2,478	1,277	1,589	8,626
COP, [W/W]	588	240	168	17	
Operating Power, [kW]	525	396	204	254	1,380
Installed Power, [kW]	788	595	306	381	2,070

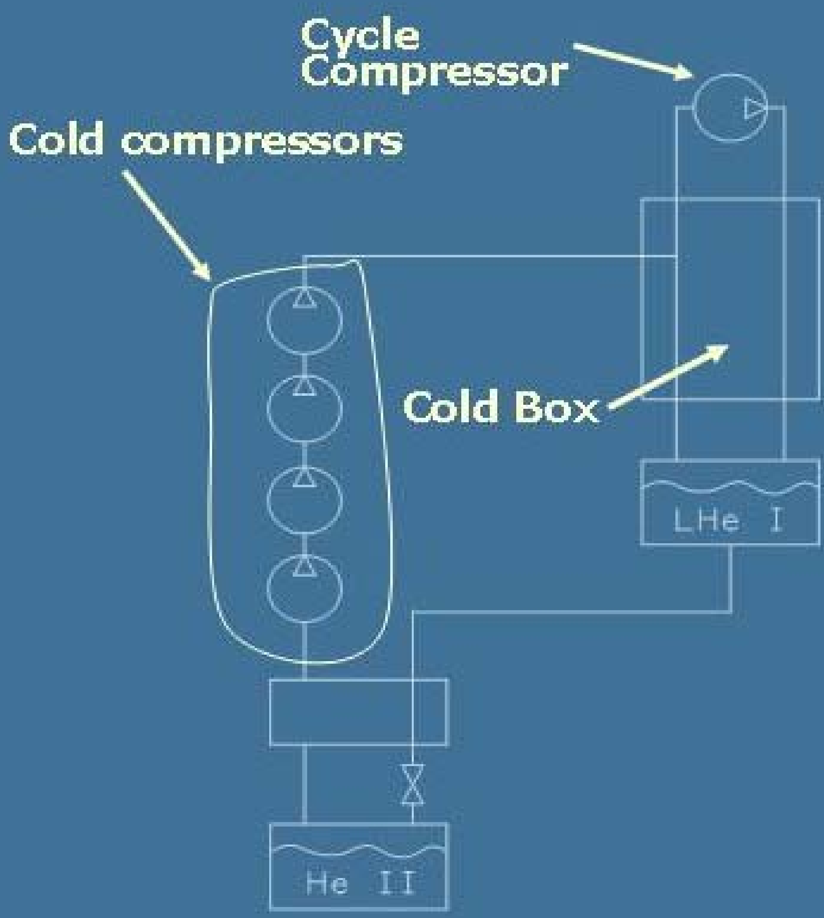
Elliptical Option	2K	4K	5K	40K	TOTAL
Capacity Required, [W]	1,019	1,067	1,377	16,789	
Overcapacity Factor	1.5	1.5	1.5	1.5	
Design Capacity, [W]	1,528	1,600	2,065	25,184	
4.5K equivalent, [W@4.5K]	3,743	1,600	1,446	1,784	8,572
COP, [W/W]	588	240	168	17	
Operating Power, [kW]	599	256	231	285	1,372
Installed Power, [kW]	898	384	347	428	2,057

Model Plant	*2K*	*4K*	*5K*	*40K*	*Total*
Plant Capacity, [W]	1,528	2,478	2,065	25,184	
4.5K equivalent, [W@4.5K]	3,282	2,478	1,277	1,589	**8,626**

Technology of Helium Refrigerators

- Over the last forty years, accelerator projects have been instrumental to push helium refrigerator technology into the direction of higher reliability, better efficiency and lower cost.
- All major components of the Proton Driver helium refrigerators have been used successfully in similar systems before
- While the design of the mechanical components is already fixed, continuous progress is going on concerning quality assurance, instrumentation, diagnostics and computer simulation of operational conditions
- The special challenge of the Proton Driver refrigeration system is to satisfy several demands of covering a wide range of heat loads. As operation at reduced capacity (RF systems are turned off) can occur for extended time periods, it's too expensive to compensate the heat load by electrical heating at 2 K

Cryogenic temperature pumping



Pros:

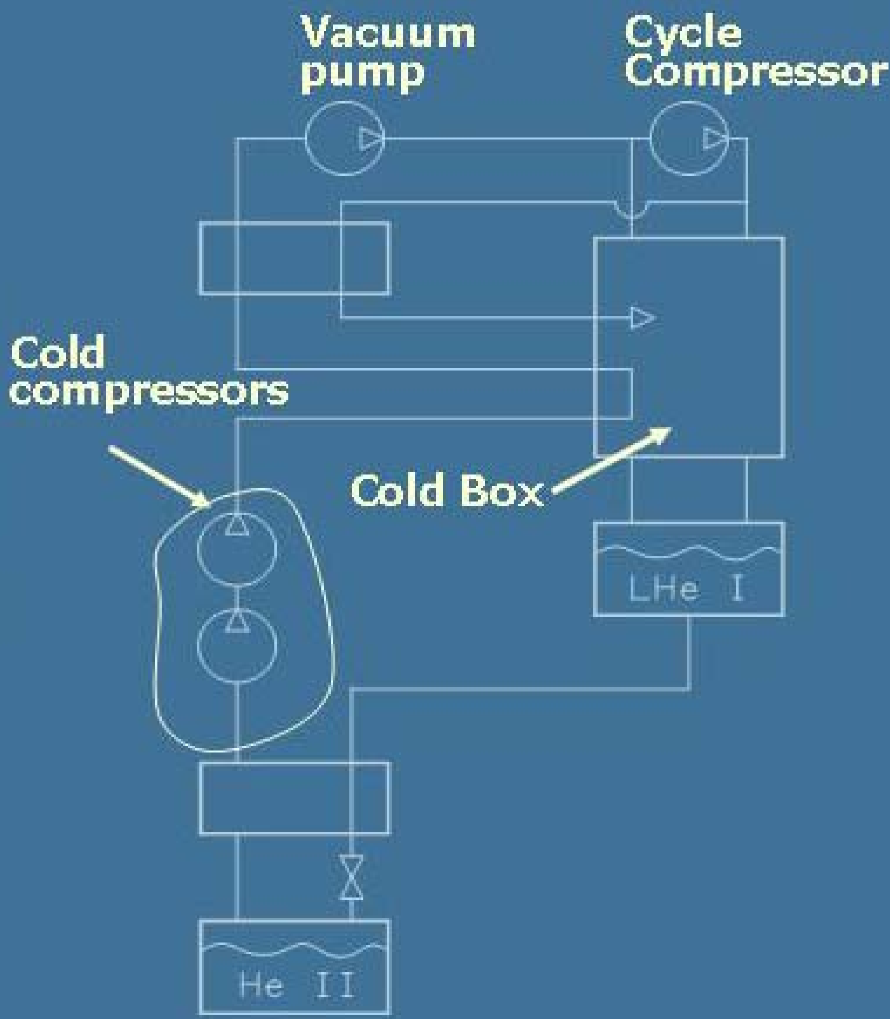
1. Unlimited cryogenic power
2. Low maintenance
3. High reliability
4. Low operation cost

Cons:

1. Narrow turn-down margin
2. Delicate stability
3. Capital cost

CEBAF – 4800 W @ 2K

Hybrid pumping



Pros:

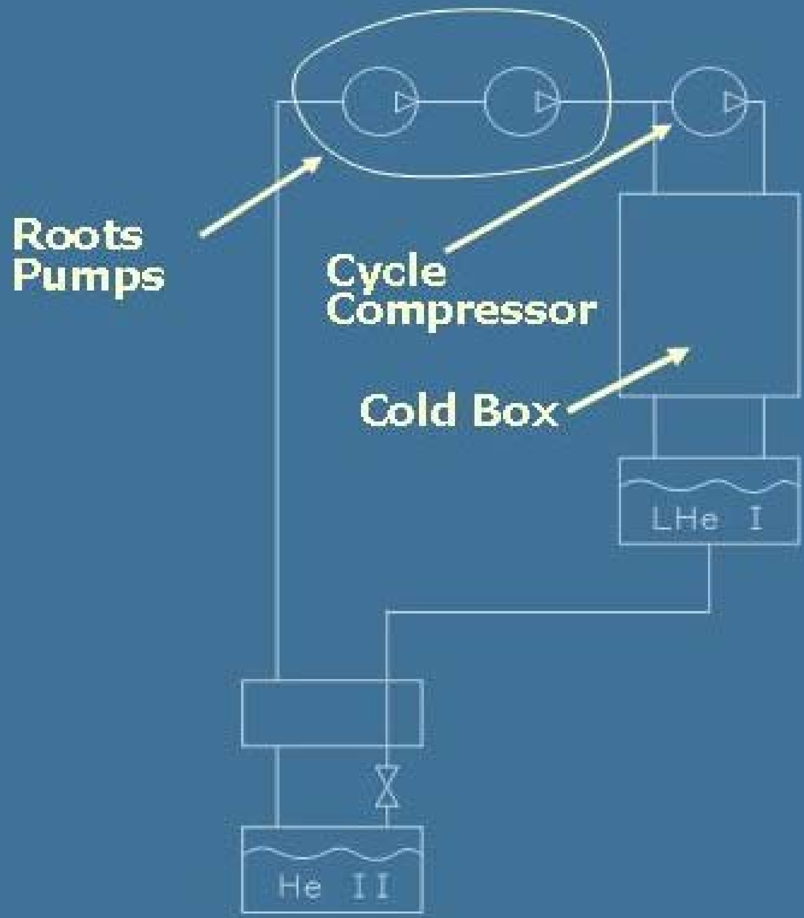
1. Unlimited cryogenic power
2. Reduced maintenance
3. Easy turndown
4. High reliability
5. Good stability
6. Low operation cost

Cons:

1. Capital cost

Largest system at CERN – 2400 W@1.8K

Room temperature pumping



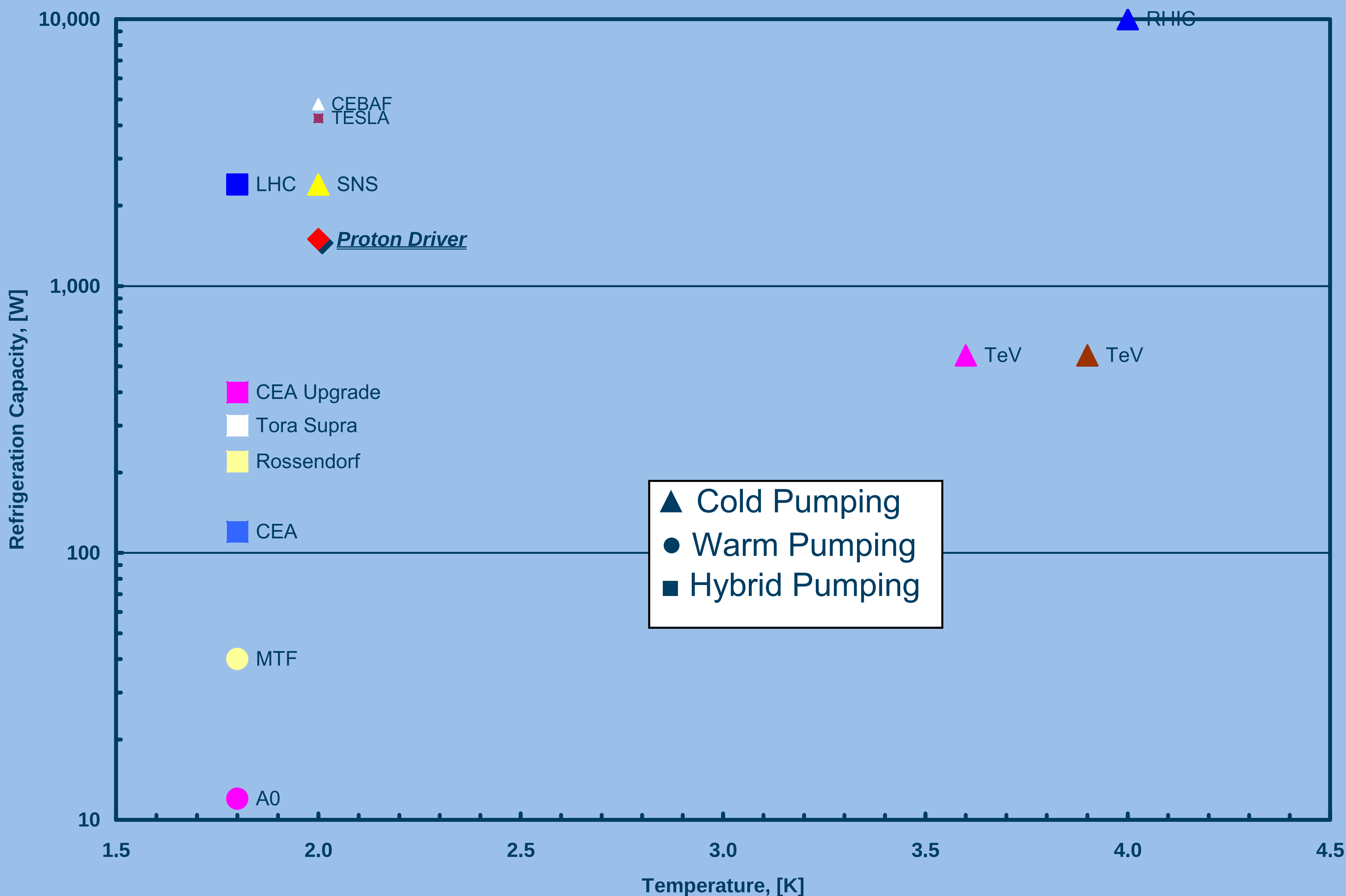
Pros:

1. Low capital cost
2. Natural stability
3. Easy turn-down

Cons:

1. Limited capacity
2. High maintenance
3. Limited operation time
4. Low reliability
5. High operation cost

Largest system was at CERN – 300 W@1.8K


10,000
1,000
100
10
Refrigeration Capacity, [W]
RHIC
CEBAF
TESLA
LHC
SNS
Proton Driver
TeV
TeV
CEA Upgrade
Tora Supra
Rossendorf
CEA
MTF
A0
Cold Pumping
Warm Pumping
Hybrid Pumping
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Temperature, [K]

Technology of Helium Refrigerators (cont 3)

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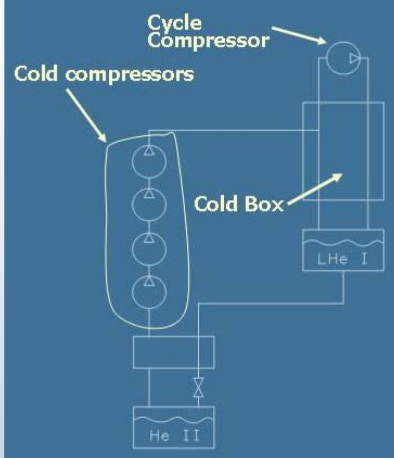
Cryogenic temperature pumping

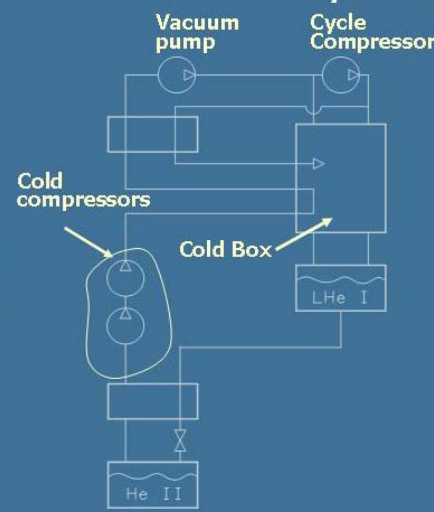


Pros:
1. Unlimited cryogenic power
2. Low maintenance
3. High reliability
4. Low operation cost

Cons:
1. Narrow turn-down margin
2. Delicate stability
3. Capital cost

CEBAF – 4800 W @ 2K

Hybrid pumping

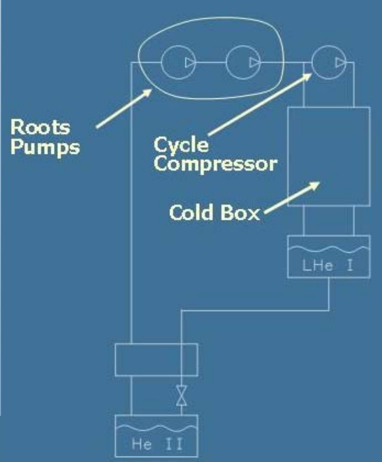


Pros:
1. Unlimited cryogenic power
2. Reduced maintenance
3. Easy turndown
4. High reliability
5. Good stability
6. Low operation cost

Cons:
1. Capital cost

Largest system at CERN – 2400 W@1.8K

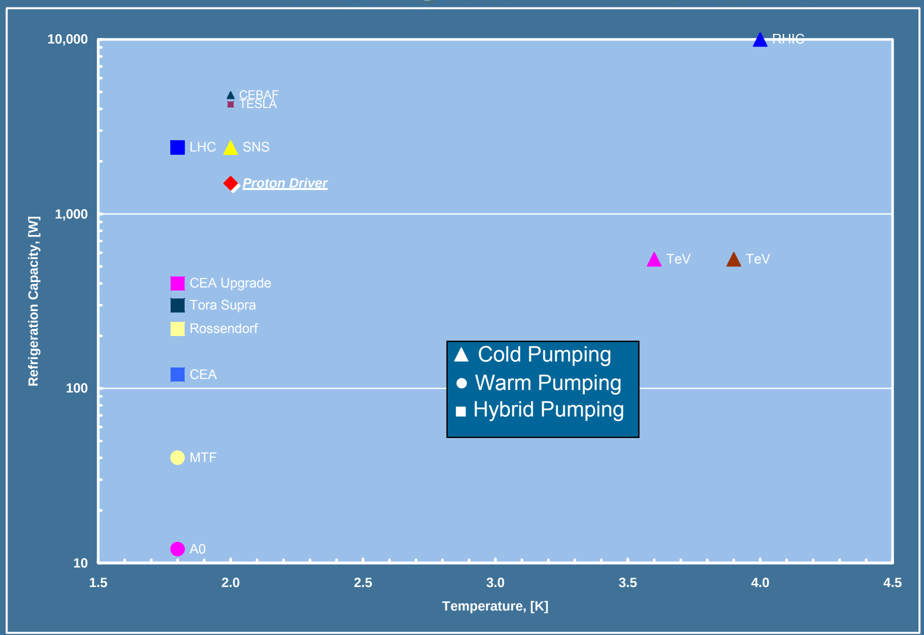
Room temperature pumping



Pros:
1. Low capital cost
2. Natural stability
3. Easy turn-down

Cons:
1. Limited capacity
2. High maintenance
3. Limited operation time
4. Low reliability
5. High operation cost

Largest system was at CERN – 300 W@1.8K



Model Refrigerator

- The model refrigerator allows
  - to get information on component sizes, number of compressors, flow rates in different loops etc
  - to get provisional data on power consumption for the specification of utility systems and the operating budget
  - to get the approximate size of components for the building layout

Conclusions:

- The design loads can be covered by a single refrigerator with a single coldbox
- The number of foreseen machines is adequate
- The power consumption estimates are reasonable
- The design leaves industry sufficient freedom to incorporate their best components

Model Refrigerator (cont)

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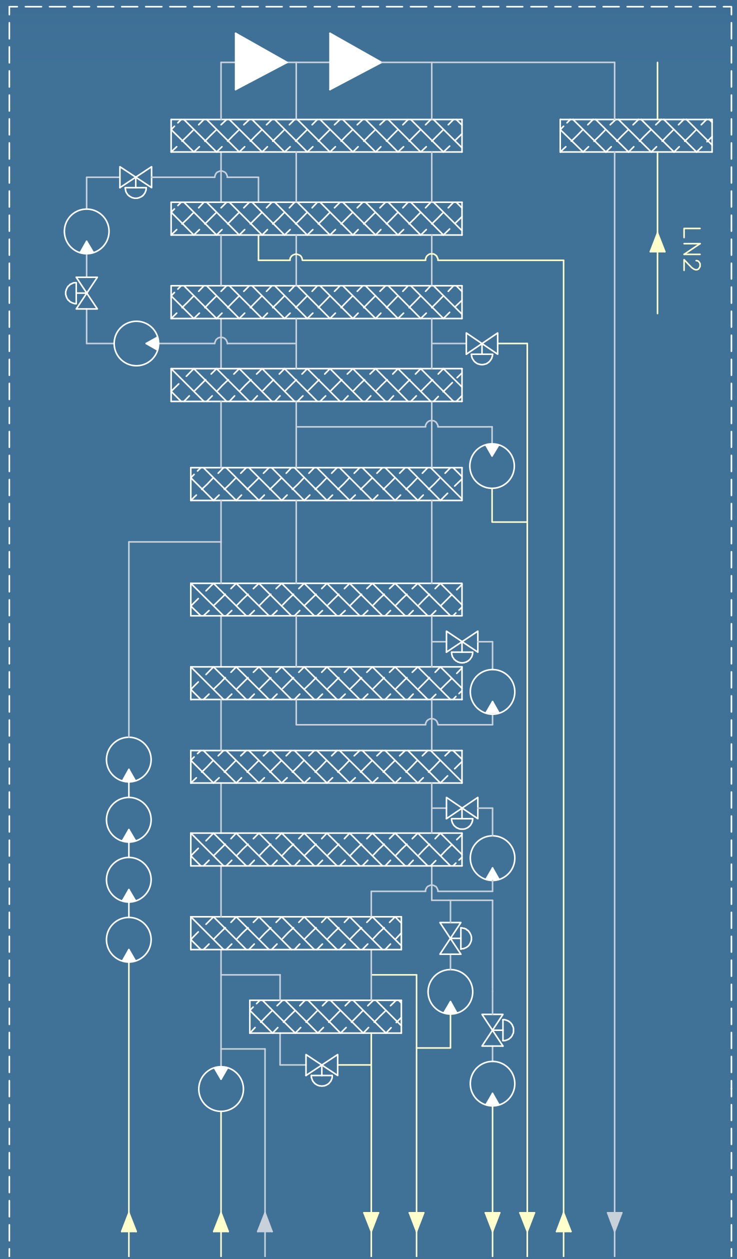
- Hybrid Plant
- Eq. Capacity 8.7 kW at 4.5K
- Multiple shield flows
- Three pressure cycle
- Two (2) first stage compressors
- Two (2)second stage compressors
- Sub-atmospheric warm stage
- Four (4) Cold Compressors
- Eight (8) turbo expanders
- Nitrogen exchanger for fast cooldown
- Good partial load (up to 60%) efficiency



Plant Controls

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- Local equipment control is a part of the new plant contract
- Process control possibly a part of the contract for the new plant
- Operator interface and utilities (data logging, plotting and alarming) could be common with other PD systems or stand alone
- If stand alone system is chosen, then interface to the other PD systems could be established

Ancillary Systems

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SNS Gas Helium Storage

Ancillary Systems

SNS LN2 Storage

Ancillary Systems

SNS LHe Storage Dewar

Ancillary Systems

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SNS Helium purifier

Ancillary Systems

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Ancillary Systems

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Ancillary Systems

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1. Gas Helium Storage – 8 x 30,000 gal tanks
2. LN2 Storage – 1 x 20,000 gal tank
3. LHe Storage – 1 x 10,000 gal tank
4. Helium purifier and recovery compressors
5. Cooling tower
6. Arc cells and hydrometers

Cryonomics

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1. Cost model based on the LHC methodology
2. Model was verified against SNS actual cost
3. Ancillary systems - based on the actual costs
4. Man power effort is estimated to be 51 [man-year]
5. Inflation and currency exchange rate included
6. No contingency is included
7. No G&A is included
8. No Linac Cryogenic instrumentation is included

Cryogenic M&S ~ $23M

Cryogenic Issues

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- Refine heat load requirements
- Efficient partial load operation
- Long strings of cryogenic modules
- Schedule and resources

Conclusions

- PD cryogenic system is technically feasible
- PD cryogenic system is financially predictable. Cost estimate is consistent with SNS actual cost, LHC project methodology, TESLA TDR, and US LCSG cost estimate approach.
- Technical and cost risks are deemed to be either low or medium/low
- Design of new cryogenic distribution components has low technical risk
- Proton Driver R&D at SMTF will assist to improve heat load requirements and optimize cost